Plant physiological and biophysical regulations of ecohydrological processes in response to strong climate variability

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Certificate of Original Authorship

I, Rong Gan declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Life Sciences/Faculty of Sciences at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Publications arising from this thesis

Journal papers directly included in this thesis

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Gan, R., Zhang, L., Wang, E., Woodgate, W., Zhang, Y., Haverd, V., Kong, D., Fischer, T., Chiew, H. S. F., & Yu, Q. (2019). Estimating ecosystem maximum light use efficiency based on water use efficiency principle. (Second round review for journal Geophysical Research Letter) (Chapter 5)

Parts of the journal papers arising from this thesis

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Peer-reviewed International Conference proceedings

Dec 2019 The 23rd International Congress on Modelling and Simulation (MODSIM), Canberra, Australia, 3-8 December 2019. An ecohydrological model for estimating streamflow, evapotranspiration and gross primary production for Australian catchments (Extended Abstract, Submitted).

APR 2019 The European Geosciences Union General Assembly (EGU), Vienna, Austria, 7-12 April 2019. Estimating Ecosystem maximum light use efficiency from water use efficiency principle (Poster presentation).

DEC 2018 The American Geophysical Union Fall Meeting (AGU), Washington D.C., USA, 10-14 December 2018. Uncertainty of transpiration estimates from a coupled water and carbon model in grassland ecosystems (Poster presentation)

Dec 2017 The 22nd International Congress on Modelling and Simulation (MODSIM), Hobart, Tasmania, Australia, 3-8 December 2017. Estimating water and carbon fluxes using a simple diagnostic model (Oral presentation).

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Glossary

ET	*evapotranspiration (mm d^{-1})*
E	*evaporation from wet surface (mm d^{-1})*
T	*transpiration from vegetation (mm d^{-1})*
GPP	*gross primary production (μmol m^{-2} s^{-1} or g C m^{-2} d^{-1})*
Q	*Streamflow (mm d^{-1})*
LE	*latent heat flux (W m^{-2})*
H	*sensible heat flux (W m^{-2})*
G	*ground heat flux (W m^{-2})*
CO_2	*carbon dioxide*
C_a	*atmospheric* CO_2 concentration (parts per million)
eCO_2	*elevated carbon dioxide concentration in the atmosphere*
G_s	*surface conductance (m s^{-1})*
G_c	*canopy conductance (m s^{-1})*
g_s	*stomatal conductance (m s^{-1})*
k_Q	*light extinction coefficient of shortwave radiation*
k_A	*light extinction coefficient of available energy*
α	*initial slope of the light response curve to assimilation rate (μmol CO_2 (μmol PAR)$^{-1}$)*
η	*initial slope of the CO_2 response curve to assimilation rate (μmol m^{-2} s^{-1} (μmol m^{-2} s^{-1})$^{-1}$)*
$V_{m,25}$	*notional maximum catalytic capacity of Rubisco per unit leaf area at 25 °C (μmol m^{-2} s^{-1})*
m	*stomatal conductance coefficient*
MODIS	*Moderate Resolution Imaging Spectroradiometer*
LAI	*leaf area index (m^2 m^{-2})*
SPAC	*soil-plant-atmosphere continuum*
LSMs	*land surface models*
VPD	*water vapour pressure deficit (kPa)*
RR	*rainfall-runoff model*
XAJ	*Xinanjiang model*
ε_{max}	*maximum light use efficiency (g C MJ^{-1} PAR)*
LUE	*light use efficiency (g C MJ^{-1} PAR)*
WUE	*water use efficiency (g C kg^{-1} H_2O)*
uWUE	*underlying water use efficiency (g C kg^{-1} H_2O $kPa^{0.5}$)*
PAR	*photosynthetically active radiation (W m^{-2})*
f_{APAR}	*fraction of vegetation absorbed photosynthetically active radiation (%)*
R_n	*net radiation (W m^{-2})*
f_{Rn}	*fraction of vegetation absorbed net radiation (%)*
f_s	*stress factor (unitless, 0-1)*
PET	*potential evapotranspiration (mm d^{-1})*
PT	*potential transpiration (mm d^{-1})*
A	*assimilation (μmol m^{-2} s^{-1} or g C m^{-2} d^{-1})*
PA	*potential assimilation (μmol m^{-2} s^{-1} or g C m^{-2} d^{-1})*

NSE	*Nash-Sutcliffe efficiency*
R^2	*coefficient of determination*
RMSE	*root mean square error*
PFT	*plant functional type*

Abstract

This thesis aims to investigate the interaction between hydrological and ecological processes by developing practical and reliable models to quantify and evaluate key water and carbon variables, therefore assist natural resources management and potential decision making implications.

The literature review stands upon the fundamental plant regulation of key terrestrial water (evapotranspiration (ET) and streamflow (Q)) and carbon (gross primary production (GPP)) exchanges and highlights the challenge and requirement of systematic understanding and quantification of these processes using simple and robust approaches considering anthropogenic climate change. Consistent findings following this motivation demonstrate that: (1) Coupled water and carbon fluxes as regulated by plant stomata can be represented by a simple and robust diagnostic model (PML_V2) for simultaneous simulation of ET and GPP at ecosystem scale (examined at 9 Australian eddy-covariance flux sites); (2) Systematic investigation of catchment water (ET and Q) and carbon (GPP) quantity and variation can be achieved by developing a simple semi-process-based ecohydrological model (XAJ-PML_V2, examined at 63 Australian catchments). Preliminary model experiment suggests a 12% increase in Q with only 4% decrease in ET, due to stomata closure in response to a 45% increase in atmospheric CO_2 concentration (anthropogenic climate change); (3) Transpiration (T) estimates as constrained by GPP (using PML_V2 model) exhibit high variation across seasons and sites (while uncertainty remains high), which can partially be attributed to spatiotemporal variations in vegetation index and precipitation (examined at 15 grasslands, 89 site-years); and (4) Coupled relationship between photosynthesis and transpiration enables water based interpretation of carbon process, leading to the development of an analytical method for estimating the maximum light use efficiency (ε_{max}) (that is key for estimating GPP) by implementing the water use efficiency principle (examined at 52 eddy-covariance flux sites across distinct photosynthetic species (e.g., C_3, C_4) and various biome types (e.g., forest, grass)).

This thesis provides systematic understanding of water and carbon processes over ecosystem and catchment scale using modelling approaches. Particularly, two ecohydrological models have been developed to simulate streamflow, evapotranspiration and gross primary production systematically. Variation and uncertainty of water estimates are investigated based on carbon constraint. An analytical method is developed to evaluate key parameter for GPP estimation based on vegetation water use. To better interpret and quantify key ecohydrological processes under anthropogenic climate change, the models built in this thesis need to be further developed through better model structure, advanced parameterization schemes or multi-data sources.

Key words: ecohydrology, water and carbon interaction, evapotranspiration, streamflow, light use efficiency, water use efficiency, model, climate change